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Potentials and Barriers

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Renewable Electrification in Kenya: Potentials and Barriers

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Abstract

Kenya mainly depends on oil and hydro sources for electricity supply, however the rivers for hydropower and their tributaries are found in arid and semi-arid areas with erratic rainfall leading to frequent problems in stable delivery of electricity in the country. As for oil-based electricity generation, this is expensive and environmentally harmful. Kenya, however, has great potential for photo voltaics (PV)-based power generation since it is located near the equator and it receives plentiful insolation. PV technology is thus a viable option for electricity generation to mitigate the aforementioned electricity supply challenges, yet the exploitation of solar PV in Kenya is still limited. This working paper analyses both the potential for integration of PV into the Kenyan electricity generation mix and the sociotechnical, economic, political, and institutional and policy barriers, which limit PV integration. These barriers can be overcome with better and more robust policy regulations, additional investments in research and development, and coordination. Most noticeably, storage solutions and other elements of flexibility need to be incorporated to balance the intermittent nature of electricity generation based on solar PV.

Key words:

PV, Integration, electricity generation mix, Kenya

1 Introduction

Nations in the developed world are opting for renewable energy as the main resource for growing power supply because of its potential to address issues of climate change [1]. Low and middle-income countries are also increasingly looking towards renewable energy as this paper focuses on Kenya. However, up until 2008, most countries had not included PV technology into their electricity generation mix [2]. One of the reasons is that PV technology lacked cost competitiveness when compared to other renewable energy sources like wind power as well as when compared to power generation based on fossil fuels.

In general, when disregarding the harmful effects of greenhouse gas (GHG) emissions, the fossil fuel-based technologies have had an upper hand over PV. Concerns however mounted over the surging increase of GHG emissions prompting governments to adopt subsidies favouring renewable energy [3]. Such concerns as well as reductions in cost of solar technology have resulted in increased uptake and technology development in parallel. The cost of PV systems in Germany for example, has been declining steadily and significantly over the past decade; this is attributed to the rapid technological development spurred by government subsidies [4]. Installed costs between 2006 and 2013 declined by an average of 16% per year. By the first quarter of 2017, the typical cost of solar PV in typical roof top applications had fallen to 1,640 EUR per kWp from over 5,000 EUR per kWp in 2006 [5]. This decrease in installation cost took place as installed capacity increased in the same time period.

Concurrently, there has been development of PV technology that has resulted in increased efficiency from 15% to over 30% [7]. The decreasing module costs combined with increasing efficiencies have resulted in a compound decrease in the cost of electricity from PV modules. Consequently, in the global context, PV has become much more competitive and the cumulative capacity of PV technology has increased significantly [8].

The diffusion of solar and other renewable energy technologies in Kenya is low, however with solar penetration rate rising from only 1% in 2010 to a still modest 3% to 4% share in 2015 [9]. Figures from the Energy Regulatory commission (ERC) of Kenya show that the total installed capacity is about 20MWp as of January 2015. This figure is marginal compared to the total installed capacity of approximately 5,000MW in Kenya but is projected to grow at 15% annually [9]. This growth is attributed to the decreasing prices and PV thus becoming more competitive. In addition to wishing to save money, consumers like the idea of being autonomous [10].

The Kenyan electricity generation mix for 2016 shows that thermal generation provided 36% of electricity; hydropower provided 35%, geothermal contributed approximately 27%, wind power 1.1%, and solar PV contributed a paltry 0.5% [11]. The total electricity consumption for Kenya in 2016 was 7.33 TWh and carbon dioxide emission from fuel combustion was at 11 Mt [11]. The Kenyan government intends to cut GHG emissions by 30 per cent by 2030 and also to meet the electricity demand through an even further expansion of renewable energy [12].

Kenya has high potential for the use of geothermal energy, but faces several challenges including rising investment charges, increasing resource exploration and expansion risks, land usage conflicts, inadequate expertise, and high investment in infrastructure due to long distances from geothermal sites to existing load centres [13].

Kenya also has great potential for PV since it is located near the equator, which provides it with a high insolation [14]. The insolation levels in Kenya and the large rural population is a stimulant for the penetration of solar power; according to [15] about 70% of the land area in Kenya has the potential of receiving approximately 5 kWh/m^2/day throughout the year with an annual mean radiation of 6.98 kWh/m^2 .

1.1 Integrated Systems Analyses

Existing literature on integration of PV in the electricity generation mix has mainly focused on Europe and United States of America. Little attention has been paid to emerging economies such as Kenya. In emerging economies such as Kenya where, electricity production and demand has yet to mature, there is room for adopting an infrastructure capable of meeting the future power demands from the outset.

In Kenya, electricity generation in the form of pumped hydroelectric power generation is seen as a viable option to replace run-of-river hydroelectric power plants whose production in susceptible to drought which result in reduced electricity generation capacity as well as outright power outages [14]. As it is, the electricity system in Kenya suffers from frequent power outages that are well documented. In a typical month, firms and homesteads connected to the grid experience on average 6.3 power outages, each lasting approximately five hours [16]. The economic cost of power interruptions is approximately 7.1% of the firms' sales; power outages therefore have a significant economic cost on businesses [16] and in turn on the Kenyan society.

There has been less emphasis on solar PV in Kenya. Specifically, no study has highlighted the potential of and possible barriers to solar PV generation where hydropower already exists.

Studies on PV in Kenya have a leaning towards ensuring access to electricity in areas located far away from the national grid as opposed to grid-connected projects [17]. This of course limits the analyses of interplay with hydropower. The only exceptions to off-grid analyses to date are viability studies by [18] in South Africa and the review conducted by [19].

A main shortcoming of PV has traditionally been the large initial investment rather than technical aspects. There have been efforts towards establishing the economic viability of solar PV in different regions of the world. A study focusing on the Middle East and North Africa regions concluded that rooftop PV systems were competitive with other energy producing plants in the region [20].

In the Kenyan context, [21] used a levelized cost of energy evaluation and established that solar power in combination with other generation technologies is competitive in relation to non-renewable energy. In spite of the high insolation levels, solar PV has mainly been used for off-grid application such as solar lanterns because of the high upfront investment costs of grid-connected solar PV systems [22]. However, currently, solar PV has been highly incentivized and prices have dropped significantly thus making it a viable option compared to diesel-fuel generators that are expensive to run [23].

The integration of PV is dependent on the temporal overlay between the electricity demand and the solar output. Clearly, solar PV is only available during the day. The only way to enhance its utility is to make investments in battery storage or combine with other sources of electricity such as wind or hydropower that either have a different temporal production profile or are dispatchable. Consequently, the problem with the PV technology is its fluctuation, which is a hindrance to a high penetration.

Hydropower, which makes up 35% of the total capacity in Kenya's electricity generation mix, offers a solution to the variability problem of solar PV as it can be used as a means of storage in a pumped hydro-electricity generation set up. Through coordination, a higher penetration of solar PV may be achieved by using hydropower to compensate for the fluctuations in PV output. Consequently, there will be less disruptions in electricity supply since there is reliance on both solar and hydropower.

1.2 Scope and Structure of the Paper

The predominant focus in the existing studies on Kenya is on the potential of PV as a renewable energy resource from a technical perspective and with a particular focus on stand-alone applications. To exploit the potential more thoroughly, there is need for proper analysis of the opportunities and barriers for integration of PV in Kenya's electricity generation mix. The scope of the paper is therefore to analyse the potentials and barriers for deployment of PV technology in Kenya's electricity generation mix.

The working paper is based on a review of the existing knowledge within the field, which is subsequently synthesized to provide a multifaceted perspective on opportunities and barriers to grid-connected PV in Kenya.

This paper is structured as follows: Section two gives the methodology, section three discusses technological barriers, section four reviews economic barriers, section five reviews institutional and policy barriers. Section six highlights the political climate, section seven provides a discussion and perspectives on the findings and section eight gives the conclusion of the paper.

2 Methodology

In this study, a systematic four-step literature review is conducted. To retrieve publications, Google scholar (which is a commonly used tool for review studies) was used.

For the first step, a combination of keywords was identified as follows: ("barriers" OR "opportunities") OR "PV". These sets of keywords were searched in the abstracts, titles and keywords of the publications from 2012 to 2017 yielding 203 publications.

In the second step, each publication was evaluated for its relevance to the integration of PV systems in the electricity generation mix, based on the abstract, title and keywords. If a publication had relevance, it was eligible for inclusion in the third step. This resulted in 102 full texts.

In the third step, the full texts were evaluated in detail for their relevance to the barriers and opportunities for integration of PV technology in Kenya's electricity generation mix. This ensured that no relevant information was missed from the publications. If a study addressed any kind of opportunity or barrier to the diffusion, it was included for analysis in the fourth step. Consequently, this resulted in 46 full texts.

Barriers to renewable energy technology (RET) penetration in general and to PV technology specifically are a global phenomenon. They appear quite similarly in extant literature, with only some country or technology specific differences. [24] has categorized major barriers to RET penetration in six categories: "market failure/imperfection, market distortions, economic and financial, institutional, technical, and social, cultural and behavioural". Examples of barriers include, for instance, lack of information and awareness, favouritism towards conventional energy production, disregard of externalities, economic unviability, clash of interests, lack of Research and Development (R&D) culture, lack of professional institutions, lack of skilled personnel/training facilities and lack of consumer acceptance of the product.

Not all the barriers identified by [25] are relevant or applicable in the Kenyan context. These categories of barriers and opportunities for success were therefore revisited and updated to make them relevant in the Kenyan context. Consequently, the range of barriers constraining the deployment of PV was categorized into technological, economic, institutional and policy and political as shown in figure 1.

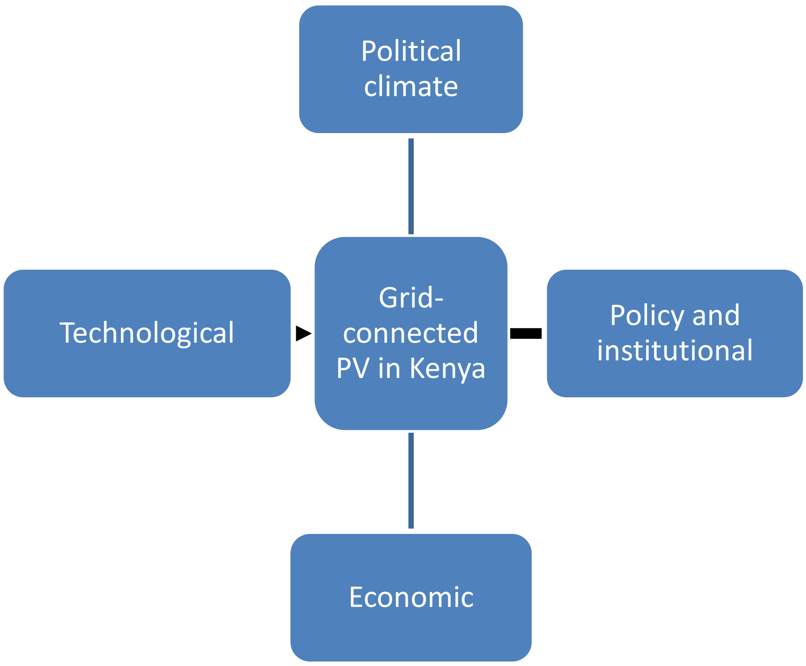

Figure 1: Analytical framework for assessing barriers and opportunities for increased integration of solar PV in Kenya.

As the fourth step in this analysis, the four categories of barriers and opportunities identified in the analytical framework presented in Figure 1 were evaluated further as follows.

3 Technological barriers:

Although PV technology has advanced tremendously in the last decades, literature shows that there are still several technical barriers to its adoption. The quality of PV systems is of vital importance for its integration. Lack of adequate knowledge is a crucial barrier that may result in improper usage and inability to maintain the systems [10]. This may create a negative perception and prevent potential customers making a decision to adopt the systems.

The advent of the PV technology in Kenya in the 1970s was mainly facilitated by donors and particularly in the 1980s, PV systems were donated to facilities such as health clinics that were off-grid [13]. During the implementation of PV in rural off-grid areas it was established, however, that there was a market for PV technology beyond the scope of health clinics and off-grid missions [17]. Thus, within two years from 2000 to 2002, households increased the purchases of PV systems from 20% to 40% of total annual PV purchases.

However, the benefits from the solar PV systems were mainly accrued by the rural middle class [26]. Consequentially, poorer rural households were sidestepped in terms of receiving subsidized PV systems [27].

With time, a focus on the rural affluent allowed the PV sector to be commercially viable without reliance on donors or subsidies. Specifically, in the 2000s, focus was on the middle-income cadre, which was propelled by reduced costs of PV systems and a desire for the middle income to watch television [26]. These advances have led to the development of an extensive electricity grid of PV schemes thereby making it possible for Kenya to be an assembly hub for PV panels [28]. Most of the development in Kenya has been in the form of stand-alone systems though, that are not part of the national grid.

The biggest technological challenge for PV in Kenya has been the lack of energy storage systems [29]. As mentioned earlier, Kenya mainly relies on run-of- river hydroelectric power supply. Battery storage solutions exist but the accompanying initial cost is prohibitive hence the need to look at development of hybrid power generation systems combining solar PV with hydropower as a viable alternative option [20].

The storage requirement is of course dependent both the composition of the rest of the electricity systems and on the share of PV. While small share of OV can be integrated with no technical issues, large-scale integration of PV sets higher demands for the flexibility of energy systems. [30] talk about the three phases of implementing RE; the introduction phase where RE merely displaces fossil-based production; the large-scale integration phase where “The integration of wind and solar power in the system becomes complex and requires consideration with regard to grid stabilisation.” Lastly, the 100 per cent renewable energy phase where “The influence on the system is complex not only with regard to differences from one hour to another but also with regard to the identification of a suitable combination of changes in conversion and storage technologies. Moreover, the challenge of operating the grid in terms of ensuring frequency and voltage stability is of major importance".

As the national Kenyan system is in the first phase – as are most other countries in the world – the integration issues of large-scale integration are not faced yet, but a strong focus on PV will eventually bring the country there. However, while this may be a slow development for the national system, for off-grid systems, the situation may very well be different. Here PV introduction can quickly bring the system to the second or even third phase with the integration challenges that follow from this.

4 Economic Barriers

The main economic barrier for PV integration is the high upfront cost and consequently, unwillingness of banks to fund such investments [31]. This is mainly because the higher construction costs might make financial institutions more likely to perceive renewables as risky, lending money at higher rates and making it harder for utilities or developers to justify the investment. Perceptions of the (high) costs associated with solar PV can be an additional barrier even if prices have come down considerably in recent years. The bulk of the cost of PV integration can be attributed to the expense of building the technology.

Cost comparisons and competitiveness of solar PV with the conventional electricity system are among the biggest barriers for adoption of solar PV in Kenya both for the utility company and for individual investors [13]. From the perspective of both the national utility company Kenya Power and independent power producers, large scale PV electricity generation without a well-functioning energy storage system maybe too expensive considering the fact these companies are also required to maintain the grid infrastructure and manage other attendant running costs [32].

To mitigate these challenges, the incumbent could consider using solar PV with run-of river hydro to create pumped hydro system; they could also sell solar modules, provide financing and grid connections or build a service relationship with individual investors. Once the domestic market grows, the installation costs will become cheaper; this could further be facilitated by training and certification of solar PV installers at the national level [33]. To boost connectivity to the grid, there should be enhanced investment in a robust electric power system that is reliable and able to meet electricity demand.

5 Institutional and Policy Barriers

Policy measures are of vital importance for large-scale introduction of PV. A lack of stability of incentives for the adoption of PV can be a significant barrier - for instance a sudden removal of existing subsidies or inconsistencies in policy measures.

Kenya has instituted policies meant to increase the integration of PV [1]. Particularly, among these policies is the Kenya Rural Electrification Master plan, the Feed-in Tariff policy and the Vision 2030 [34]. The government has also made a move towards ensuring that entrepreneurs willing to invest in solar PV are catered for [35]. In fact, as early as 2008, Kenya developed the feed-in tariff policy meant to ensure market stability for investors in PV. The feed-in tariff made it possible for independent power producers to deliver power from wind and hydro sources to the national grid. In 2012, the feed-in tariff policy was revised to include solar power [22]. However, these policies have not translated to higher installed PV largely because the policies are not well coordinated during implementation or at worst they are not implemented at all.

Kenya has an interconnected electricity grid operated and run (monopolized) by Kenya Power and Lighting Company Limited. The process of grid connection for new PV systems is long and complicated which discourages potential investment in PV power generation[14].

5.1 Creation of a PV Market Driven by Public and Private Firms

Solar PV technologies have become an increasingly attractive technology for bringing sustainable energy services to millions of individuals worldwide, promising low carbon emissions, simplicity of operations and affordable pricing [32]. In the 1980s, donors provided the requisite resources to support the activities of PV actors within and outside Kenya. Arguably, without the support from the donors, it is unlikely that Kenya would have a successful PV market. In developing countries whereby, there is limited access to electricity grids, solar home systems with mobile phone charging capability are being adopted widely [17].

The PV market in Kenya has evidenced use of Solar Home Systems, which has been considered the most successful off-grid solar market in the developing economies [32].

5.2 Role of Research and Development Programs in the Deployment of Solar PV

Globally, China is a powerhouse for solar technology [36]. The advent of the solar PV in China was in the 1950s with the state playing a key role in its deployment. In 2001, China possessed thirty research institutes and universities that were working collaboratively to develop the materials used in PV cells [37]. Notably, key domestic manufacturers of PV process equipment have emerged with a number of firms being tasked with PV system design, technology research and development, manufacturing of the components as well as sales and after-sales service. Concisely, most of the firms have been involved in the rural electrification program by the government [38]. Besides, there is in-house research and development whereby firms devoted a tenth of their annual turnover to facilitate their technological capabilities and the competitiveness in the PV [39].

Compared to China, the United Kingdom is a small player in the PV. Nonetheless, UK is credited with a broad range of skills and interests. The majority of universities in UK are active in R & D of PV technology [39].

In view of the extant literature, instances of research and development in the PV in Kenya are close to none. [40] noted that the Kenya Industrial Research and Development Institute is engaged in researching on the development of low carbon and climate resilient technologies such as solar PV. The authors noted that Migori, Bungoma, Kirinyaga, Embu and Samburu were among the counties that were surveyed for low carbon technologies. This study concluded that a policy brief should be developed to spur the Pico solar market in Kenya. Pico refers to the smallest portable photovoltaic systems mainly typified by rechargeable battery. From the ensuing discussion, efforts have been made towards Research and Development for PV in Kenya such as the energy research centre at Strathmore University. Nonetheless, the challenge is that these efforts are not enough to increment the integration of PV in Kenya because Kenya has limited grid-connected PV systems.

5.3 University-Industry Linkages: The Role of Universities

Institutions of higher learning are instrumental players in both national and regional innovation systems [41]. In the recent past, universities have received substantial attention with regard to their role in innovation and spurring economic development. Universities are credited with major advances in scientific research and the creation of innovations with impact on the society.

Universities in Kenya have historically played a role in its National Innovation System mainly in development of renewable energy. In fact, Strathmore University is the brainchild of Strathmore Energy Research Centre (SERC), which offers professional training, project development, and technical research in the renewable energy sector [21]. Since its inception, SERC has been at the forefront in implementing innovative pilot projects with the intention to bring renewable energy into Africa.

Furthermore, the centre for research on New and Renewable Energies at Maseno University has also been instrumental in ensuring that there is renewable energy locally and regionally with special emphasis on rural application [40]. The centre focuses on harnessing bio-energy, geothermal, solar and wind energy. Additionally, the energy technology programmes offered in Kenyan universities are meant to develop individuals with the capacity to address the national and global challenges in the energy sector. Although the curricula in some universities maybe out dated and in need of review, this indicates that university-industry linkages exist and maybe utilized to foster increased integration of PV in electricity generation mix.

6 Political Climate: Experiences from Africa

Under- or over-prioritization of investments in certain sectors in relation to others is not usually based on technical decisions but rather involves political choices and prioritizations. Large-scale PV projects are essentially large infrastructure projects that are typically highly political in nature and that involve a multitude of actors with competing interests and negotiations across various levels. For example, [42] argue that the push for RE in Kenya is not necessarily being driven by environmental concerns, but rather by the need to provide access to electricity to the highest number of people within the shortest time possible These authors highlight the tensions that come from pursuing the multiple objectives of ‘growth’, ‘inclusiveness’ and ‘sustainability’.

The African continent has a rich source of solar energy and in the recent years, PV is becoming a viable alternative source of electricity for both small and large-scale application in Africa [38]. Similar to Kenya, solar PV deployment in most other countries in Africa has mainly been driven by rural (off-grid) electrification. As opposed to most of the African nations, Morocco saw the need for spurring PV on a larger scale for electricity generation at an early stage. In fact, a Moroccan integrated solar project was launched that comprised of solar and wind technologies that complement each other. Besides, the government has commissioned a 500 MWp plant in 2018 [43].

In 2015, Rwanda is at an early stage of solar power integration according to [1]. At the time, there were at most eight companies that were mainly donor driven whose scope was to install solar systems in government hospitals and schools. According to the authors, there was a growing market for solar PV mainly among the private households.

Despite this, Rwanda possesses the largest grid connection in East Africa ahead of Kenya and Tanzania [1]. Nonetheless, there has been a tremendous growth in PV for off-grid Rwandan rural electrification since 2009 [26]. Further development of the technology was due to a strong focus on the Rwandan vision 2020, which puts emphasis on renewable energy technology.

Besides, the Monetary Growth and Poverty reduction policy in Rwanda states that the government in collaboration with the private sector should facilitate the distribution and the sale of solar PV systems and further provide a regulatory environment that is conducive for the rapid integration of PV [35]. Experience from Rwanda and Morocco could be used to inspire policies in Kenya to help foster increased integration of solar PV in the country.

7 Discussion

Solar PV can offer an economical alternative to the current use of fossil fuel-based power plants. At the moment, the utility (Kenya Power) enjoys the sole monopoly of managing costs of connecting PV systems to the grid and they manage the grid single handedly.

Another technological challenge for integration of PV technology is the temporal match with the demand; solar power is available during the day and there must be a viable way of harnessing it for use when the sun is not out or to integrate PV with other technologies. For policy-makers and international organizations keen to reduce carbon emissions and dependence on imported fuels, the deployment of hydro resources alongside solar PV is a viable option for many sub-Saharan African countries. It is here important to remember the role played by hydropower sources, which supply up to 35% of the end-user electricity demand in Kenya.

This working paper does not fully explore the potential value of hydro storage in Kenya for the integration of PV, but as noted, to reach the second phase in renewable energy integration, considerable attention must be placed on the temporal characteristics of the entire energy system. Thus, a full accounting of hydropower production is needed so that full exploitation of hydro will lessen the need for other means of storage such as batteries and this may in turn result in a decrease in overall costs. Solar PV may also be attractive in non-hydro based systems where diesel is the primary source of base load power.

There are conflicting standpoints and expectations of policy makers and utilities that constitute institutional and policy barriers. Incumbent electricity companies in Kenya and elsewhere are likely to favour maintaining the status quo since they have made investments in the existing electricity generation system. This creates path dependence and lock-in effect [24]. At the same time, there are new forms of electricity generation such as PV generation that try to break the lock-in and this clashes with the current Kenyan electricity regime that is mainly based on hydro and fossil fuels. Resistance from the utility or other industry players can be sensed in the context of path dependence and lock-in, and therefore undermines integration of renewable sources of energy [21].

On the other hand, the supportive policies advanced by the Kenyan government towards renewable energy have contributed towards a growing interest among citizens related to solar energy. There is a range of different kinds of support instruments in use, such as conducive environment for investment, innovative financing schemes, exemptions from value added tax and import taxes, standardized power purchase agreements and feed-in-tariffs which have lead to the growth of PV market in Kenya [44].

These policies have raised the important point that dynamic support structures for renewable energy technologies can aid in increasing their market penetration. A period of high subsidy may be particularly important to establish early growth in market share, but should be followed by adjustments in subsidies to prevent markets from growing too quickly. At the same time, [24] reminds that support must go beyond financial measures to be sustainable. [24] found that one-off investment support or tax rebates were preferable to feed-in tariffs, as they were deemed more cost efficient and were likely to instil greater confidence in investors.

In addition, research institutions play a critical role in integration of PV systems through building of local capacity to handle installation, operation and maintenance of PV systems. As highlighted earlier, research and development has played a key in the advancement of PV technology in countries such as China. Kenya needs to invest more in research and development in order to scale up electricity generation from PV technology and therefore increase economic competitiveness of solar PV.

These linkages can be extended to collaborations between Kenya and the international community. In most African countries integration of solar PV systems (mainly small-scale) has been driven by donor-supported projects aimed at serving specific needs for electricity [1]. The donor community has facilitated acquisition of solar systems to local communities and institutions by providing the requisite resources. Arguably, availability of resources from PV actors from outside Kenya may also help scaling up of PV technology in the country.

8 Conclusions:

This working paper has discussed the potentials and barriers for integration of PV technology in Kenya based on a literature review. To achieve high installed capacities of solar PV, significant changes must occur in the Kenyan electricity sector. Most noticeably, storage solutions and other elements of flexibility need to be incorporated to balance the intermittent nature of electricity generation based on solar PV. This is particularly eminent for large-scale deployment of PV technology in Kenya. An important complement between hydro and solar PV to address storage challenge was proposed in this investigation.

Such a future hybrid system represents a complete transformation from the current scenario will be required. A variety of technical, economic, institutional, political barriers have been pointed out which prevent further increase of PV technology. Some of the technological barriers identified include:

- Lack of adequate knowledge on PV technology
- Lack of energy storage systems
- Poor quality of PV systems

An important economic barrier identified is:

- High upfront costs and unwillingness of banks to fund PV investments

Some of the institutional and policy barriers identified are:

- Lack of stability incentives for adoption of PV
- Long and complicated grid connection process
- Grid monopoly enjoyed by Kenya Power and Lighting Company Limited

These barriers can be overcome with new and robust policy regulations, additional investments in research and development, better regulation of the electricity sector and improved coordination between key actors.

While this analysis focused on the potential for solar PV in the Kenyan system, the results may be applicable to other sub-Saharan African countries, many of whom are faced with the same challenges: growing demand for electricity, insufficient generating capacity, and long lead times and extensive financial investments required for planned generation projects. As a result, many countries have turned to short-term expensive solutions such as diesel plants. Further, the other characteristics that may make solar PV a favorable option in Kenya such as abundant solar resource and large capacities of untapped reservoir hydro- power are also present across the continent.

Bibliography

[1] U. E. Hansen, M. B. Pedersen, and I. Nygaard, “Review of solar PV policies, interventions and diffusion in East Africa,” *Renew. Sustain. Energy Rev.*, vol. 46, pp. 236–248, 2015.

[2] A. Rose, R. Stoner, and I. Perez-Arriaga, “Prospects for grid-connected solar PV in Kenya: A systems approach,” *Appl. Energy*, vol. 161, no. 2016, pp. 583–590, 2016.

[3] A. D. Adam and G. Apaydin, “Grid connected solar photovoltaic system as a tool for green house gas emission reduction in Turkey,” *Renew. Sustain. Energy Rev.*, vol. 53, pp. 1086–1091, Jan. 2016.

[4] T. Lang, D. Ammann, and B. Girod, “Profitability in absence of subsidies: A techno-economic analysis of rooftop photovoltaic self-consumption in residential and commercial buildings,” *Renew. Energy*, 2016.

[5] A. S. M. Zahid Kausar, A. W. Reza, M. U. Saleh, and H. Ramiah, “Energizing wireless sensor networks by energy harvesting systems: Scopes, challenges and approaches,” *Renewable and Sustainable Energy Reviews*. 2014.

[6] A. C. Look, “Solar Energy Support in Germany A Closer Look,” no. July, 2014.

[7] “Fukushima Renewable Energy Institute,” 2014. [Online]. Available: http://www.aist.go.jp/fukushima/en/outline/. [Accessed: 23-May-2017].

[8] Q. Xu, H. Li, G. Hao, and Y. Ding, “Study on Several Influencing Factors of Performance Evaluation Index of Photovoltaic System,” *J. Clean Energy Technol.*, vol. 4, no. 6, pp. 424–429, 2016.

[9] ERC, “Energy Regulatory Commission - Biomass,” 2015. [Online]. Available: http://erc.go.ke/index.php?option=com_fsf&view=faq&catid=2&faqid=14. [Accessed: 01-Apr-2017].

[10] E. Karakaya and P. Sriwannawit, “Barriers to the adoption of photovoltaic systems: The state of the art,” *Renew. Sustain. Energy Rev.*, vol. 49, pp. 60–66, 2015.

[11] EIA, “International Energy Outlook 2016-World energy demand and economc outlook - Energy Information Administration,” *International Energy Outlook* , 2016. [Online]. Available: https://www.eia.gov/outlooks/ieo/world.cfm. [Accessed: 29-Mar-2017].

[12] H. Belmili, M. Haddadi, S. Bacha, M. F. Almi, and B. Bendib, “Sizing stand-alone photovoltaic-wind hybrid system: Techno-economic analysis and optimization,” *Renew. Sustain. Energy Rev.*, 2014.

[13] R. B. and M. A. Phillips, “Renewable energy incentives in Kenya: Feed-in-tariffs and Rural Expansion,” 2016.

[14] C. S. Lai and M. D. McCulloch, “Levelized cost of electricity for solar photovoltaic and electrical energy storage,” *Appl. Energy*, vol. 190, pp. 191–203, 2017.

[15] F. Oloo, L. Olang, and J. Strobl, “Spatial Modelling of Solar Energy Potential in Kenya,” *Int. J. Sustain. Energy Plan. Manag.*, vol. 06, pp. 17–30, 2016.

[16] A. Ramirez, “Energy Access,” no. March, pp. 1–2, 2016.

[17] N. Opiyo, “Modelling PV-based communal grids potential for rural western Kenya,” *Sustain. Energy, Grids Networks*, vol. 4, pp. 54–61, 2015.

[18] C. L. Azimoh, *Sustainability and Development Impacts of off-grid electrification in developing countries. An assessment of South Africa’s rural electrification program*. 2016.

[19] P. Sharma, A. W. Walker, J. F. Wheeldon, K. Hinzer, and H. Schriemer, “Enhanced efficiencies for high concentration, multijunction PV systems by optimizing grid spacing under nonuniform illumination,” *Int. J. Photoenergy*, vol. 2014, p. 582083, 2014.

[20] C. Werner and C. Breyer, “Analysis of mini-grid installations: an overview on system configurations,” *27th Eur. Photovolt. Sol. Energy Conf. Exhib.*, no. SEPTEMBER 2012, pp. 3885–3892, 2012.

[21] I. P. Da Silva, G. Batte, J. Ondraczek, G. Ronoh, and C. a Ouma, “Diffusion of solar energy technologies in rural Africa: trends in Kenya and the LUAV,” *Proc. from 1st Africa Photovolt. Sol. Energy Conf. Exhib. 27-29 March 2014, Durban, South Africa*, vol. 1, no. March, pp. 27–29, 2014.

[22] M. O. E. A. P. Republic of Kenya, “Strategic plan,” 2014.

[23] A. M. Aris and B. Shabani, “Sustainable Power Supply Solutions for Off-Grid Base Stations,” pp. 10904–10941, 2015.

[24] M. Child, T. Haukkala, and C. Breyer, “The role of solar photovoltaics and energy storage solutions in a 100% renewable energy system for Finland in 2050,” *Sustain.*, vol. 9, no. 8, 2017.

[25] M. Child, T. Haukkala, and C. Breyer, “sustainability The Role of Solar Photovoltaics and Energy Storage Solutions in a 100 % Renewable Energy System for Finland in 2050,” pp. 1–25, 2017.

[26] C. Kirubi, A. Jacobson, D. M. Kammen, and A. Mills, “Community-Based Electric Micro-Grids Can Contribute to Rural Development: Evidence from Kenya,” *World Dev.*, vol. 37, no. 7, pp. 1208–1221, 2009.

[27] J. Simiyu, S. Waita, R. Musembi, A. Ogacho, and B. Aduda, “Promotion of PV uptake and sector growth in kenya through value added training in PV sizing, installation and maintenance,” *Energy Procedia*, vol. 57, pp. 817–825, 2014.

[28] A. Tigabu, A. Kingiri, F. Odongo, R. Hanlin, M. H. Andersen, and R. Lema, “Capability development and collaboration for Kenya ’ s solar and wind technologies : analysis of major energy policy frameworks,” no. January, pp. 1–13, 2017.

[29] P. Munro, G. van der Horst, S. Willans, P. Kemeny, A. Christiansen, and N. Schiavone, "Social enterprise development and renewable energy dissemination in Africa: The experience of the community charging station model in Sierra Leone," *Prog. Dev. Stud.*, vol. 16, no. 1, pp. 24–38, 2016.

[30] B. V. Mathiesen *et al.*, "Smart Energy Systems for coherent 100% renewable energy and transport solutions," *Applied Energy*. 2015.

[31] R. Energy, "Renewable Energy Policies in a Time of Transition," 2018.

[32] P. Rolffs, D. Ockwell, and R. Byrne, "Beyond technology and finance: pay-as-you-go sustainable energy access and theories of social change," *Environ. Plan. A*, vol. 47, no. 12, pp. 2609–2627, 2015.

[33] N. Opiyo, "A survey informed PV-based cost-effective electrification options for rural sub-Saharan Africa," *Energy Policy*, vol. 91, pp. 1–11, 2016.

[34] M. Parthasarathy, V. A. and Anandaraj, *Vision – 2030*. Government of Kenya, 2011.

[35] I. Nygaard, U. E. Hansen, and M. B. Pedersen, "Measures for diffusion of solar PV in selected African countries," *J. Clean. Prod.*, vol. under revi, no. December, pp. 0–15, 2015.

[36] Y. Tian and C. Y. Zhao, "A review of solar collectors and thermal energy storage in solar thermal applications," *Appl. Energy*, vol. 104, pp. 538–553, 2013.

[37] Z. Zhao, K. Venayagamoorthy, T. Burg, R. Groff, and P. Belotti, "Optimal Energy Management for Microgrids," 2012.

[38] U. Elmer and M. Brix, "Review of Solar PV Market Development in East Africa," *UNEP Risø CentreUNEP Risø Cent. Work. Pap. Ser.*, no. 12, 2014.

[39] N. Marigo, T. J. Foxon, and P. J. Pearson, "Comparing innovation systems for solar photovoltaics in the United Kingdom and in China," pp. 1–17.

[40] L. M. Maclean and J. N. Brass, "Foreign Aid , NGOs and the Private Sector : New Forms of Hybridity in Renewable Energy Provision in Kenya and Uganda," *Afr. Today*, vol. 62, no. 1, pp. 57–82, 2015.

[41] J. Osman, "Utilizing Solar Energy In King Faisal Specialist Hospital & Research Center Riyadh, Saudi Arabia," *Master Thesis, Sch. Archit. Grad. Cent. Plan. Environ. Pratt Inst.*, no. December, 2012.

[42] U. Elmer, C. Gregersen, R. Lema, D. Samoita, and F. Wandera, "Energy Research & Social Science Technological shape and size : A disaggregated perspective on sectoral innovation systems in renewable electri fi cation pathways," no. July 2017, 2018.

[43] K. Attari, A. Elyaakoubi, and A. Asselman, "Performance analysis and investigation of a grid-connected photovoltaic installation in Morocco," *Energy Reports*, vol. 2, no. December 2015, pp. 261–266, 2016.

[44] Government of Kenya (Ministry of Energy and Petroleum), "Draft National Energy and Petroleum Policy," pp. 1–130, 2015.